Ball lightning: A puzzle for contemporary science

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Outline of lecture

- History of BL observation
- Properties of BL
- Experiments for BL generation in a laboratory
- BL theory
- Model of BL based on spherically symmetric plasma oscillations
- Summary


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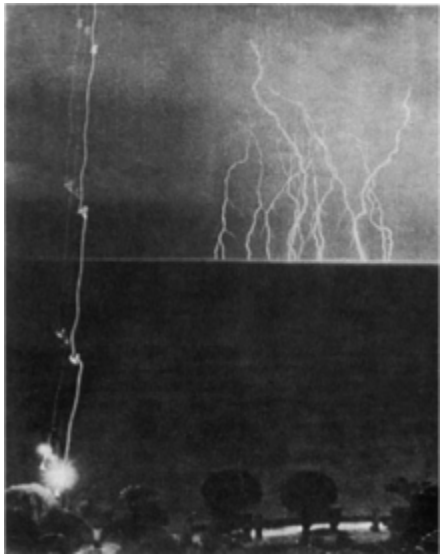
Long-lived natural plasma structures: Ball Lightning (BL)



One of the first BL observations

VPon Sunday the 21. of *October* last, In the Parish Church of *Withycombe* in *Devonshire* neare *Dartmoores*, there fell in time of Divine Service a strange darkenesse, increasing more and more, so that the people there assembled could not see to reade in any booke, and suddenly in a fearefull and lamentable manner, a mighty thundering was heard, the ratling whereof did answer much like unto the sound and report of many great Cannons, and terrible strange lightening therewith, greatly amazing and astonishing those that heard and saw it, the darkenesse increasing yet more, till they could not (in the interim) see one another; the extraordinarie lightning came into the Church so flaming, that the whole Church was presently filled with fire and smoke, the smell whereof was very loathsome, much like unto the sent of brimstone, some said they saw at first a great ball of fire come in at the window and passe thorough the Church, which so much affrighted the whole Congregation that the most part of them fell downe into their seates, and some upon their knees, some on their faces, and some one upon another, with a great cry of burning and scalding, they all giving up themselves for dead.

England 1638

Further BL observations in the past

Fig. 2. — Le globe de feu dans la salle.

Videos of BL

Recent BL observation

PRL 112, 035001 (2014) PHYSICAL REVIEW LETTERS week ending 24 JANUARY 2014

Observation of the Optical and Spectral Characteristics of Ball Lightning

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(Received 26 April 2013; revised manuscript received 13 November 2013; published 17 January 2014)

Ball lightning (BL) has been observed with two slitless spectrographs at a distance of 0.9 km. The BL is generated by a cloud-to-ground lightning strike. It moves horizontally during the luminous duration. The evolution of size, color, and light intensity is reported in detail. The spectral analysis indicates that the radiation from soil elements is present for the entire lifetime of the BL.

- BL was occasionally recorded in China during the linear lightning observation
- Its spectrum was reported to contain the lines of Fe, Si, Ca, N
- Some experts are skeptical about this observation

Properties of BL

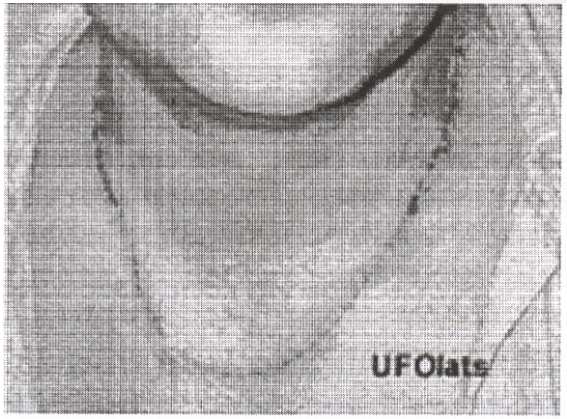
- Most frequently it appears during a thunderstorm
- Size: ~ several centimeters
- Life time can be up to several minutes
- Energy: from kJ to several MJ
- BL can freely pass through tiny holes

BL energy

- B.L.Goodlet case described in J. Instn. Elect. Engrs. **81**, 1 (1937)
- BL having a size of “a big orange” entered to the barrel with 18 lts. of water.
- Water started to boil and about 1 lt has evaporated.
- The total energy of this BL is about 8 MJ!
- Assuming that R = 10 cm, we get the energy density of BL 15 kJ/cm^3
- Such energy content is equivalent to 10^4 eV per molecule
- It is 3 orders of magnitude bigger than the energy of chemical reactions

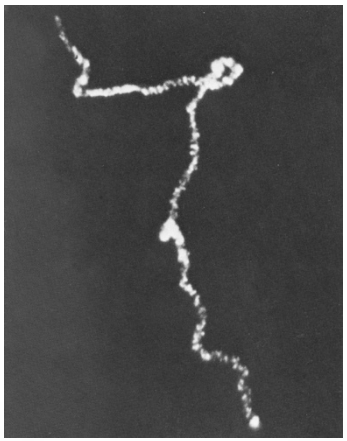
BL hazards

- BL can induce strong eddy currents
- BL can destroy home appliances, electronics, computers etc.
- In many cases it is lethal for animals (Gomes, 2012)
- BL can be dangerous for human beings



BL as a stepped leader?

- Typical cloud to earth tension is about 10 times less than that required to initiate a spark discharge (Raizer, 1992)
- The nature of stepped leader is unknown
- A pilot, whose airplane occasionally entered to a thundercloud, observed thousands of BLs around his the aircraft (Grigoriev, 2010)
- BL is a stepped leader which initiates a linear lighting?
- Bead lightning



Gatchina discharge

Technical Physics Letters, Vol. 28, No. 2, 2002, pp. 164–166. Translated from Pis'ma v Zhurnal Tekhnicheskoĭ Fiziki, Vol. 28, No. 4, 2002, pp. 81–86.

The Optical Properties of Long-Lived Luminous Formations

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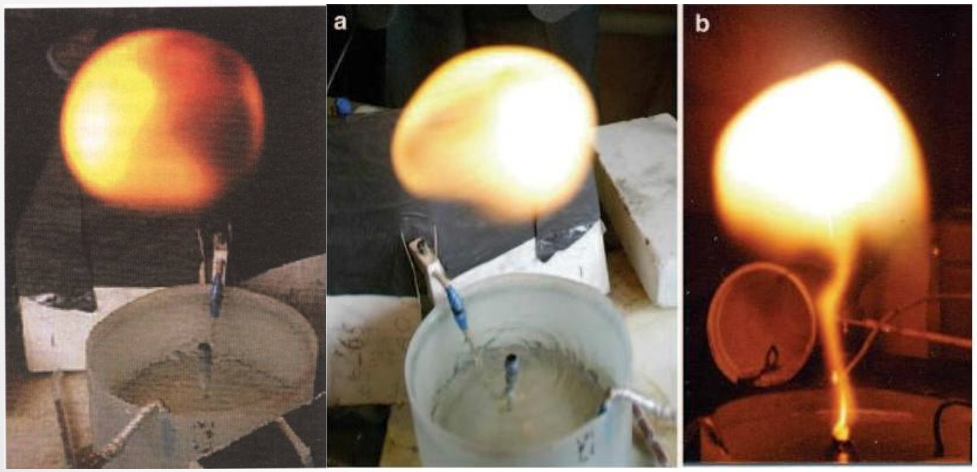
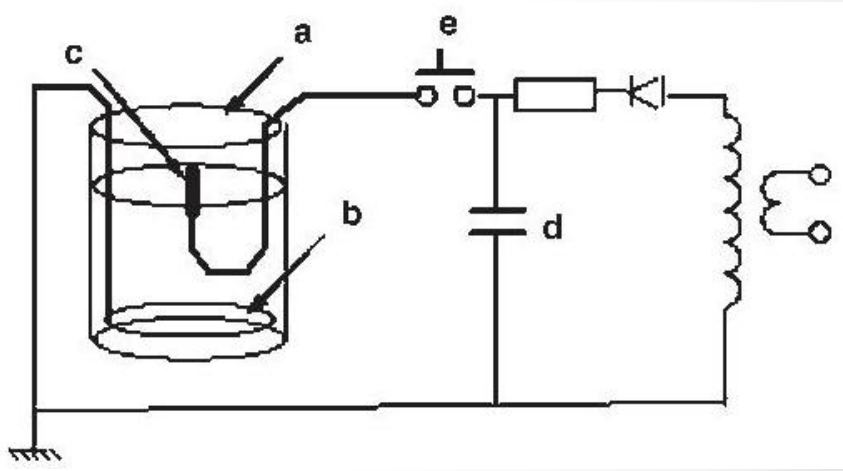
Received April 4, 2001; in final form, September 4, 2001

Abstract—Luminous formations initiated by electric discharge appear differently depending on the intrinsic luminosity, external illumination, and the background color. These formations simultaneously exhibit four colors: red, yellow, violet, and blue. These colors are known to be typical of the ball lightning (BL) possessing, according to the available statistics [1], a short lifetime. At the same time, it was stated [2] that there is BL of two types: short- and long-lived. Based on the results obtained, it is suggested that the short-lived BL must also exhibit all four colors simultaneously.[1]

- The properties of GD resemble a natural BL
- GD was independently reproduced by in Germany by Versteeg et al. (2008) and in USA by Stephan et al. (2013)





Setup of the Gatchina discharge: (a) polyethylene vessel; (b) ring electrode; (c) central electrode; (d) battery capacity of 0.6 mF; and (e) discharger

Electric discharges in silicone

PRL **98,** 048501 (2007) PHYSICAL REVIEW LETTERS week ending 26 JANUARY 2007

Production of Ball-Lightning-Like Luminous Balls by Electrical Discharges in Silicon

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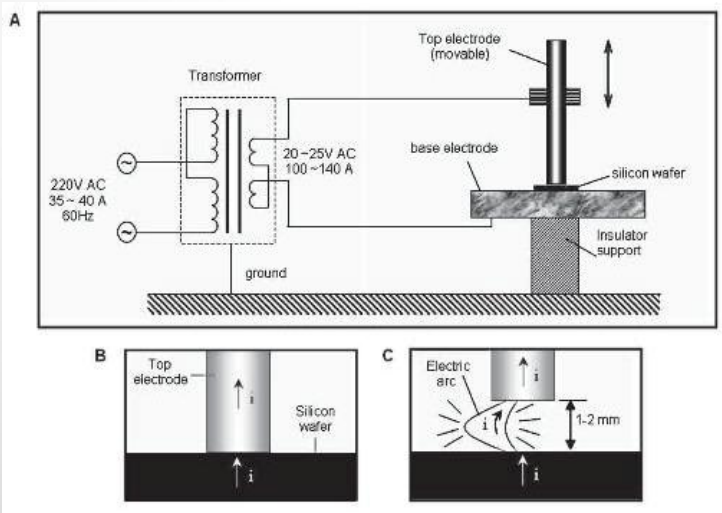
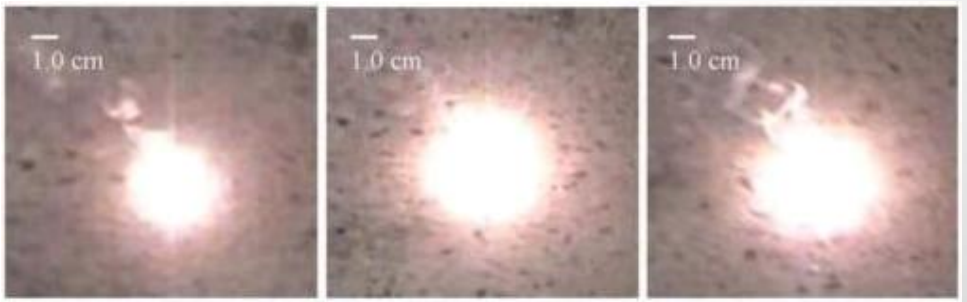
(Received 10 June 2006; published 24 January 2007)

We performed electric arc discharges in pure Si to generate luminous balls with lifetime in the order of seconds and several properties usually reported for natural ball lightning. This simple experiment does not rely on energy sources and excitation mechanisms that are improbable in the natural phenomenon and clearly demonstrates the role of vaporization and oxidation of Si, as proposed by the Abrahamson-Dinniss theory for ball-lightning formation.

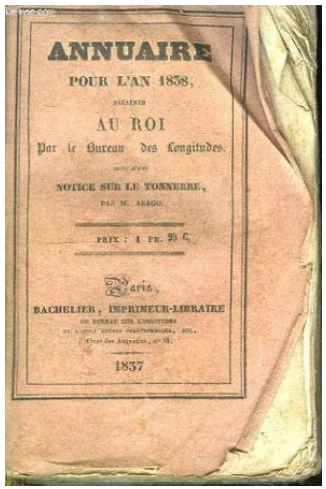


- Long-lived autonomous objects, which resemble natural BL, were obtained
- These objects leave nano-sized traces on external materials. It means that the actual size of an object is small
- The results of these experiments were confirmed in Belorussia by Lazarouk et al. (2006) and in Japan by Ito & Cappelli (2012)



The first scientific study of BL

- François Arago was the first who performed the scientific study of BL («Notices scientifiques sur le tonnere», 1837)

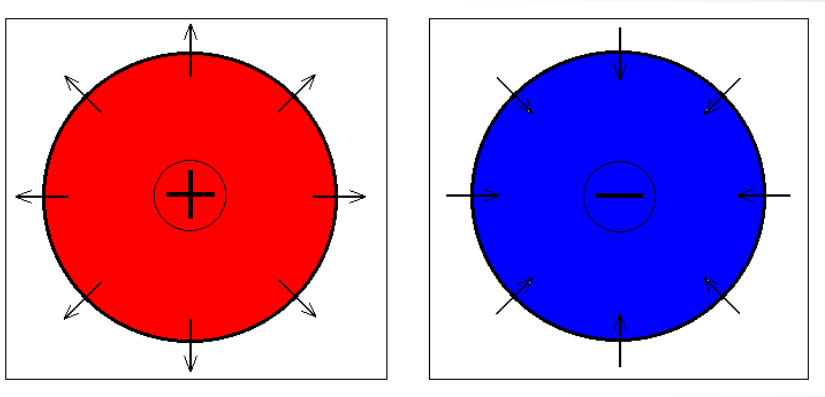


Can classical physics be applied for the description of BL?

- A.Vlasov in 1978 pointed out that using classical Boltzmann and Gibbs statistics for the description of BL results in the contradiction: the mass of BL turns out to be infinite
- Unstructured plasma recombines during ~ 1 ms, whereas BL exists for up to several minutes
- There should be magnetic fields for the plasma confinement inside BL. However in this case BL will intensively radiate and lose energy

Model of BL based on radial oscillations of charged particles

- BL core can contain one or several spherically symmetric plasma oscillations
- This BL description were performed in frames of both classical and quantum approaches
- Classical description: stable spatial Langmuir solitons (e.g., Kuznetsov, et al., 1986)
- Quantum description: quantum plasma hydrodynamics (e.g., Haas, 2011) and complex plasmas (e.g., Bonitz, et al., 2014)



Analogous model was considered by

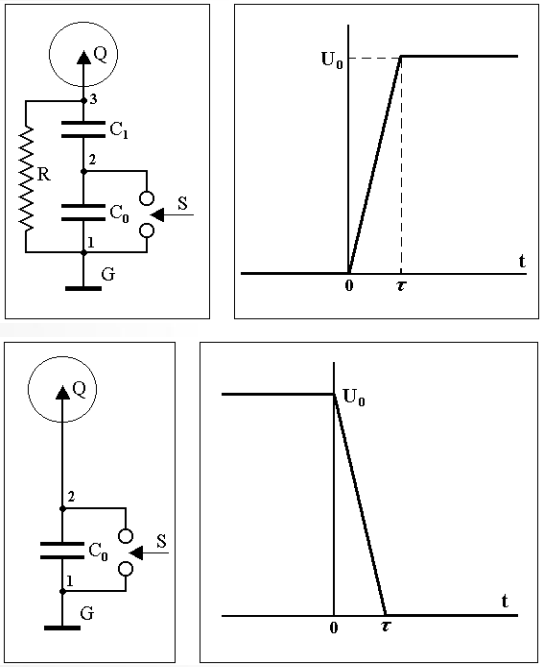
- Ostapenko & Tolpygo (1984)
- Fedele (1999)
- Shmatov (2003)
- Tennakone (2011)

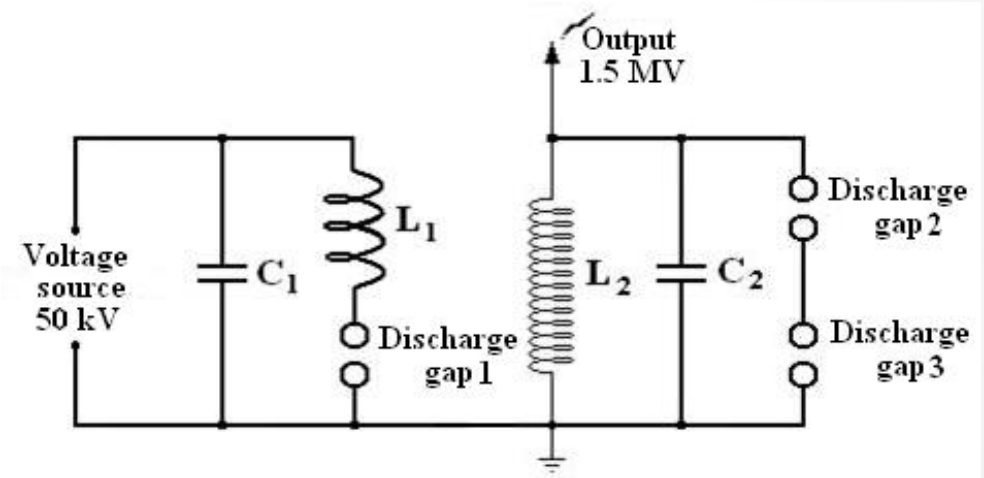
Description of some of the BL properties in frames of the proposed model

- Spherically symmetric plasma oscillations do not emit electromagnetic waves. Thus the system does not lose energy and it is stable.
- The size of plasma structures is tiny: (10^{-6} – 10^{-5}) cm. This length scale is obtained in both classical (nonlinear plasma hydrodynamics) and quantum (nonlinear quantum plasmas) approaches. It can explain the possibility of BL to pass through small holes. The observed dimensions of BL, ~ cm, probably are due to some auxiliary effects. It is like a halo around a small and dense core.
- Charged particles (ions), involved in plasma oscillations, can form bound states or pairs, owing to the exchange of a virtual acoustic wave. Probably these pairs behave like superfluid condensate. It will result in the reduction of ohmic loses in the system and the enhancement of its life time.
- Separate plamoids can attract each other owing to the quantum exchange interactions. Thus the existence of composite structure is possible. It can explain the fact that sometimes BL can divide into self similar parts. Therefore BL is likely to have a complex structure.
- The model of a composite plasma structure can account for the visible radiation of BL: it results of the decay of plasma oscillations in a small number of elementary plasmoids, whereas the majority of them is stable.

The schemes of possible experimental installations for the generation of radial oscillations of plasma

The genetation of spherical plasma structure requires very high frequencies $\nu > 10^9$ Hz





Possible applications: electronic warfare, nonlethal weapons (war on terrorism), etc.

Publications

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- **M. Dvornikov**, *"Attractive interaction between ions inside a quantum plasma structure"*, J. Plasma Phys. **81**, 905810327 (2015), arXiv:1311.6875.
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- **M. Dvornikov**, *"Pairing of charged particles in a quantum plasmoid"*, J. Phys. A **46**, 045501 (2013), arXiv:1208.2208.
- **M. Dvornikov**, *"Effective attraction between oscillating electrons in a plasmoid via acoustic waves exchange"*, Proc. R. Soc. A **468**, 415 – 428 (2012), arXiv:1102.0944.
- **M. Dvornikov**, *"Quantum exchange interaction of spherically symmetric plasmoids"*, J. Atm. Sol.-Terr. Phys. **89**, 62 – 66 (2012), arXiv:1112.0239.
- **M. Dvornikov**, *"Axially and spherically symmetric solitons in warm plasma"*, J. Plasma Phys. **77**, 749 – 764 (2011), arXiv:1010.0701.
- **M. Dvornikov**, *"Formation of bound states of electrons in spherically symmetric oscillations of plasma"*, Phys. Scr. **81**, 055502 (2010), arXiv:1002.0764.
- **M. Dvornikov** & S. Dvornikov, *"Electron gas oscillations in plasma: Theory and applications"*, in 'Advances in Plasma Physics Research, Vol. 5', ed. by F. Gerard (NY, Nova Sci. Publ., 2006), pp. 197 – 212, physics/0306157.

I am for the pluralism in science!

- The analysis of the observed properties of BL (life time, energy, size, etc.) points out that we are likely to deal with glowing structures in the atmosphere having different nature (Rakov & Uman 2003, Keul 2013).
- Thus it is impossible to explain all the observational data in frames of one model.

Some alternative models of BL

- Kapitsa 1955: Energy feeding from outside
- Shafranov 1957: Bunch of plasma confined by its own magnetic field
- Bergström 1973, Stakhanov 1973, Mesenyashin 1991: Intraction of dipole moments
- Smirnov 1977, Turner 1994, Abrahamson & Dinnis 2002, Bychkov 2010: Chemical reactions
- Smirnov 1993: Aerogel
- Rañada & Trueba 1996: Magnetic field of nontrivial configuration
- Torchigin & Torchigin 2007: Light circulating inside a spherical region

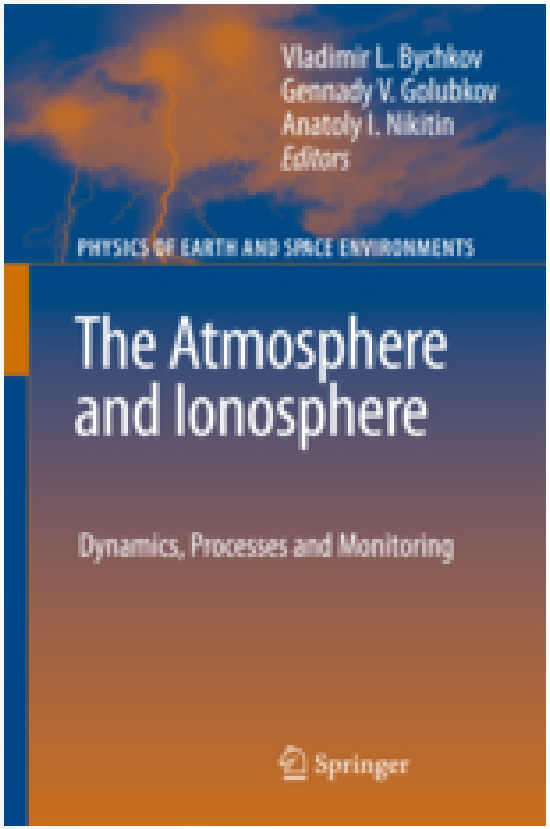
Exotics

- Dijkhuis 1980, Zelikin 2008: Superconducting plasma
- Neugebauer 1937, Kulakov et al. 1991: Quantum condensate
- Vlasov & Yakovlev 1978: Plasma confinement by acoustic waves
- Altschuler et al. 1970, Ratis 2005: Micro-dose decay of radioactive elements
- Manykin et al. 1983, Gilman 2003: Rydberg substance
- Ashby & Whitehead 1971: Annihilation of antimatter brought by meteorites or cosmic rays
- Rabinowitz 1999: Micro black holes

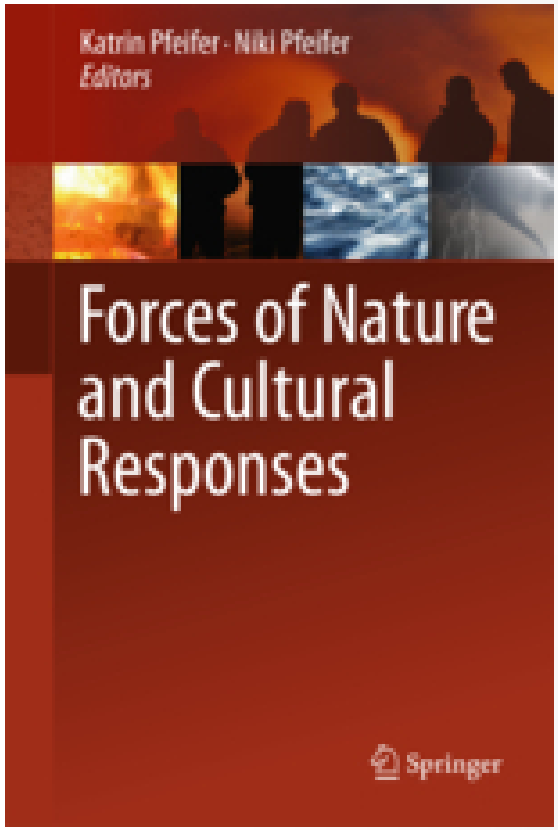
Skepticism

- Faraday 1839: BL does not have "… anything to do with the discharge of ordinary electricity"
- Lord Kelvin 1888: After-images left on the retina caused by a linear lightning discharge.
- Cooray & Cooray 2008: Optical hallucinations caused by epileptic seizures.
- Than 2010: Hallucination induced by magnetic stimulation of the brain's visual cortex or the eye's retina.

Literature on BL



Bychkov et al. (Springer, 2010 & 2014)

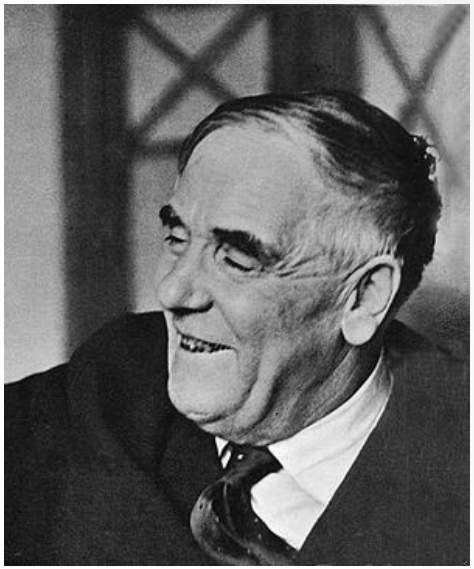


Doe & Keul (Springer, 2013)

Summary

- The history of the BL observations is reviewed
- I described the basic BL properties
- Some recent experiments to reproduce laboratory BL are presented
- Various theoretical models of BL are outlined
- The model based on spherically symmetric plasma oscillations is presented

P.L. Kapitsa:
"If I had the second life, I would devote it to the study of **BALL LIGHTNING**"



Pyotr Leonidovich Kapitsa or Peter Kapitza (1894 – 1984) was a leading Soviet physicist and Nobel laureate in 1978 "for his basic inventions and discoveries in the area of low-temperature physics".

Acknowledgements

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